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ANTI-CD18 ANTIBODIES IN STROKE

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RELATED APPLICATION

This is a non-provisional application filed under 37 CFR 1.53(b)(1), claiming priority under USC Section 119(e) to provisional Application Serial No. 60/009308 (to be assigned) filed on January 23, 1996.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to the use of anti-CD18 antibodies for treating stroke. In particular, it relates to the use of anti-CD18 antibodies for improving clinical outcome by increasing cerebral blood flow and/or reducing infarct size in focal ischemic stroke caused by obstruction of a main cerebral artery.

Description of Related Art

Stroke is a general term for acute brain damage resulting from disease of blood vessels. This presents a serious problem to society, with about 500,000 people dying from or becoming permanently disabled by stroke in the United States each year. Stroke can be classified into two main categories: hemorrhagic stroke (resulting from leakage of blood outside of the normal blood vessels) and ischemic stroke (cerebral ischemia due to lack of blood supply); this application is primarily concerned with the latter.

The three main mechanisms of ischemic stroke are thrombosis, embolism and systemic hypoperfusion (with resultant ischemia and hypoxia). In each of these types of stroke, the area of the brain that dies as a result of the lack of blood supply thereto is called an infarct. Obstruction of a cerebral artery resulting from a thrombus which has built up on the wall of a

brain artery is generally called *cerebral thrombosis*. In *cerebral embolism*, the occlusive material blocking the cerebral artery arises downstream in the circulation (*e.g.* an embolus is carried to the cerebral artery from the heart). Because it is difficult to discern whether a stroke is caused by thrombosis or embolism, the term *thromboembolism* is used to cover both these types of stroke. *Systemic hypoperfusion* may arise as a consequence of decreased blood levels, reduced hematocrit, low blood pressure or inability of the heart to pump blood adequately.

When symptoms of stroke last less than 24 hours and the patient recovers completely, the patient is said to have undergone a transient ischemic attack (TIA). The symptoms of TIA are a temporary impairment of speech, vision, sensation or movement. Because a TIA is often thought to be a prelude to full-scale stroke, patients having suffered a TIA are candidates for prophylactic stroke therapy with anticoagulation agents (*e.g.,* coumarin and heparin) or antiplatelet agents (such as aspirin and ticlopidine) for example. Thrombolytic agents, such as tissue plasminogen activator (t-PA), have been used in the treatment of thromboembolic stroke. These molecules function by lysing the thrombus causing the ischemia. Such drugs are believed to be most useful if administered as soon as possible after acute stroke (preferably within 3 hours) in order to at least partially restore cerebral blood flow in the ischemic region and to sustain neuronal viability. In that such drugs exacerbate bleeding, their use in hemorrhagic stroke is contra-indicated.

A family of adhesion glycoproteins present on leukocytes is called the *integrin* family. This integrin family includes LFA-1 (CD11a/CD18), Mac-1 (CD11b/CD18) and p150,95 (CD11c/CD18). A further member of this family CD11d/CD18 has recently been reported. Danilenko *et al., J. Immunol.* 155:35-44 (1995). Each of these heterodimers has a unique α-chain (CD11a, b, c or d) and the invariant β-chain (CD18). CD18 integrins located on leukocytes may bind to intercellular adhesion molecule-1 (ICAM-1) which is expressed on vascular endothelium and other cells, thereby mediating leukocyte adhesion and transendothelial migration.

It has been noted that CD11a and CD18 are upregulated in leukocytes from patients who have undergone ischemic stroke or a TIA. Kim *et al., J. Neurolog. Sci.* 128(1):45-50 (1995). Schroeter *et al., J. Neuroimmunology* 55(2):195-203 (1994) found that increased expression of ICAM-1 on vessels and leukocytes occurred following cerebral ischemia induced by permanent occlusion of the middle cerebral artery (MCA) in the rat.

The role of cell adhesion molecules in brain injury following *transient* MCA occlusion in the rat has been studied (Matsuo *et al., Brain Research* 656:344-352 (1994)). Matsuo *et al.*

inserted a nylon thread from the lumen of the external carotid artery (ECA) to that of the right internal carotid artery (ICA) in order to occlude the origin of the right MCA. The occlusion was transient; after 1 hour, the nylon thread was removed to allow complete reperfusion of the ischemic area via the right common carotid artery (CCA). Anti-CD11a (WT1), anti-CD18 (WT3) and anti-ICAM-1 (1A29) antibodies were administered before ischemia and immediately after reperfusion. These researchers found that treatment with individual antibodies against cell adhesion molecules reduced edema formation, infarct size and neutrophil accumulation following reperfusion.

Others have investigated the effects of antibodies against cell adhesion molecules in such transient stroke models. Zhang *et al., Brain Research* 698:79-85 (1995) studied the effects of anti-CD11b and anti-CD18 monoclonal antibodies in ischemia/reperfusion injury, wherein the antibodies were administered upon and after transient MCA occlusion (the origin of the MCA was transiently blocked with a surgical nylon filament). Mori *et al., Stroke* 23(5): 712-718 (1992) studied the effects of the anti-CD18 IB4 antibody in their baboon model of reversible MCA occlusion. In this model, arterial obstruction was achieved by inflating an extrinsic MCA balloon to 100µl. Reperfusion occurred following balloon deflation. See, also, Chopp *et al., Stroke* 25(4):869-876 (1994) and Chen *et al., Annals of Neurology* 35(4): 458-463 (1994) concerning an anti-CD11b antibody in a transient cerebral ischemia model. Chopp *et al.,* and Chen *et al.,* advanced a surgical nylon suture into the ICA to block the origin of the MCA. Reperfusion was accomplished by withdrawing the suture until the tip cleared the ICA lumen.

Takeshima *et al., Stroke,* 23(2):247-252 (1992) found that the anti-CD18 antibody 60.3 did *not* afford protection from severe focal ischemia and reperfusion in a transient focal cerebral ischemia model in cats. *Takeshima et al.* used a microvascular clip to occlude the MCA and occluded CCAs by tightening previously placed ligatures.

Lindsberg *et al. J. Neurosurg.* 82:269-277 (1995) subjected rabbits to severe spinal cord ischemia (by inflating the balloon of a catheter tip which had been introduced in the abdominal aorta) followed by 30 minutes of reperfusion at which time either: (1) vehicle, (2) anti-CD18 antibody, or (3) anti-CD18 antibody and platelet-activating factor (PAF) antagonist were administered to the animals. Recovery of motor function was improved by the anti-CD18 antibody, but no further improvement was induced by the PAF antagonist.

It has been observed that while an anti-CD18 antibody reduced neurologic deficits in the reversible spinal cord model (involving a snare ligature occluding device), it was unable to do so in an irreversible microsphere model. Clark *et al., Stroke* 22(7): 877-883 (1991). Clark *et al.*

4

conclude that leukocytes potentiate their effect in central nervous system injury via reperfusion injury. With respect to anti-CD11b antibodies, Chopp *et al., Stroke* 25(1):267 (1994) report that benefit from administration of such antibodies was observed under conditions of transient, but not permanent, MCA occlusion in rats. See, also, Jiang *et al., Neuroscience Research Communications* 15(2):85-93 (1994). Clark *et al., J. Neurosurg* 75(4):623-627 (1991) also observe that while anti-ICAM-1 produced a significant reduction in neurological deficits in the reversible spinal cord ischemia model, such therapeutic benefit was not seen in the irreversible brain ischemia model. Similar findings in relation to anti-ICAM-1 antibodies have also been reported by Zhang *et al., Stroke* 26(8):1438-1442 (1995).

Bowes *et al., Neurology* 45:815-819 (1995) evaluated the ability of monoclonal antibodies directed against ICAM-1 and CD18 to enhance the efficacy of thrombolysis in a rabbit cerebral embolism stroke model. In this model, numerous small blood clots (formed by fragmenting a clot with a tissue homogenizer) were injected into the rabbit's carotid circulation in order to achieve embolization. Neurologic function in each animal was evaluated 18 hours following embolization on a three point scale: (1) normal activity; (2) abnormal activity; or (3) death. The amount of clot necessary to produce permanent neurologic damage in 50% of the rabbits (ED_{50}) was determined for each treatment group. Bowes *et al.,*found that when administration of anti-CD18 or anti-ICAM-1 was delayed until 15 or 30 minutes after embolization, a statistically significant improvement in neurologic function was *not* observed. See also Bowes *et al., Experimental Neurology* 119(2):215-219 (1993) in relation to earlier work by this group regarding anti-ICAM-1 and t-PA in their rabbit cerebral embolism stroke model.

Bednar *et al., Stroke* 23(1):152 (1992) describe a rabbit model of thromboembolic stroke wherein the arterial occlusion (an autologous blood clot delivered to the anterior cerebral circulation) is not removed during the experiment. Rabbits received either anti-CD18 antibody IB4 (1mg/kg), or vehicle, 30 minutes following the thromboembolic event. Following embolization, the animals were studied for a total of 4 hours, including an initial 45 minutes of systemic hypotension. No statistically significant difference in cerebral blood flow (CBF) or infarct size between IB4 and vehicle treated animals was seen. However, IB4 did attenuate intracranial hypertension in this model.

It is an object of the present invention to provide a method for improving clinical outcome in acute ischemic stroke by increasing cerebral blood flow and/or reducing infarct size. Furthermore, it is an object of the invention to provide an alternative to thrombolytic therapy for treating thromboembolic stroke, particularly where thrombolytic therapy has been unsuccessful

5

or is contra-indicated, as is the case where the patient to be treated is taking aspirin, or where the time delay from the onset of stroke to diagnosis is such that thrombolytic therapy is not recommended. Other objects will be apparent from the description which follows.

SUMMARY OF THE INVENTION

This application is based on the unexpected finding that anti-CD18 antibodies can lead to a significant increase in cerebral blood flow and/or reduction in brain infarct size in focal ischemic stroke, in the absence of removal of the arterial obstruction.

Accordingly, the invention provides a method for treating stroke in a mammal (*e.g.* focal ischemic stroke caused by obstruction of a main cerebral artery) which comprises the step of administering an amount of CD18 antagonist and/or CD11b antagonist to the mammal which is effective for increasing cerebral blood flow and/or reducing cerebral infarct size in the mammal. In the method, the arterial obstruction (generally a single thrombus or embolus) is not removed by mechanical means (*e.g.* by surgically removing the obstruction) or chemical means (*e.g.* by using a thrombolytic agent to dissolve the arterial obstruction). Furthermore, the recipient of the CD18 or CD11b antagonist is not subjected to extraneous systemic hypotension (*e.g.,* via controlled exsanguination) during the method as was the case in Bednar *et al., Stroke* 23(1):152 (1992).

Preferably the antagonist is an anti-CD18 antibody, such as a humanized $F(ab')_2$ fragment. Conveniently, the antagonist is administered to the mammal in the form of a pharmaceutically acceptable formulation, such as those elaborated in more detail herein.

The preferred mode of administration of the antagonist is by bolus intravenous dosage. In certain embodiments of the invention, the antagonist may be administered at least once a time between about 15 minutes to about 20 hours and preferably between about 30 minutes to about 12 hours from the onset of focal ischemic stroke. Single or multiple dosages may be given. Alternatively, or in addition, the antagonist may be administered via continuous infusion.

In another aspect, the invention relates to a method for treating ischemic stroke caused by systemic hypoperfusion or hypoxia in a mammal (*e.g.* resulting from cardiac arrest or drowning) which comprises the step of administering a therapeutically effective amount of CD11b antagonist and/or CD18 antagonist to the mammal. The preferred antagonist for use in this method is an anti-CD18 antibody. Preferably, the method results in an increase in cerebral blood flow and a decrease in infarct size resulting from the systemic hypoperfusion.

In yet another embodiment, the invention provides a method for increasing cerebral blood flow and/or reducing infarct size in focal ischemic stroke caused by obstruction of a main cerebral artery which comprises the step of administering a therapeutically effective amount of

CD18 and/or CD11b antagonist to the mammal at least once at a time more than 15 mins (*e.g.* more than 30 mins) and preferably less than 24 hours from the onset of focal ischemic stroke in the mammal. In the method, the mammal being treated is not subjected to extraneous systemic hypotension as described in Bednar *et al., Stroke* 23(1):152 (1992). Preferably the antagonist is an anti-CD18 antibody which is administered at least once at a time between about 30 minutes to about 12 hours from the onset of focal ischemic stroke.

According to the method of the previous paragraph, a therapeutically effective amount of a thrombolytic agent (such as t-PA) may be co-administered to the mammal either before, after, or simultaneously with, the CD11b or CD18 antagonist. Preferably, the antagonist is administered to the mammal prior to administration of the thrombolytic agent. According to this method, the thrombolytic agent may be administered to the mammal more than about 3 hours after the onset of ischemic stroke (*e.g.,* at least once within about 3-8 hours and preferably within about 3-5 hours from the onset of stroke). The thrombolytic agent may be administered by one or more bolus doses or by continuous infusion, for example.

The invention also provides articles of manufacture and kits for use in the above methods.

Brief Description of the Drawings

Fig. 1 is a bar graph depicting brain infarct size (% hemisphere infarcted) in embolized rabbits following treatment with MHM23 (anti-CD18) and t-PA (n=5); MHM23 alone (n=5); t-PA alone (n=10) or saline solution control (n=10) as described in Example 1 (mean +/- standard error of the mean).

Fig. 2 depicts regional cerebral blood flow (CBF; cc/100gm/min) over time in embolized rabbits following treatment with MHM23 (anti-CD18) and t-PA (n=5); MHM23 alone (n=5); t-PA alone (n=10) or saline solution control (n=10) as described in Example 1. MHM23 or saline solution control was administered 1 hour following embolization. t-PA or saline solution control was administered by continuous infusion over hours 3-5 following embolization (mean +/- standard error of the mean).

Fig. 3 illustrates intracranial pressure (ICP; mm Hg) in embolized rabbits following treatment with MHM23 (anti-CD18) and t-PA (n=5); MHM23 alone (n=5); t-PA alone (n=10) or saline solution control (n=10) as described in Example 1. MHM23 or saline solution control was administered 1 hour following embolization. t-PA or saline solution control was administered by continuous infusion over hours 3-5 following embolization (mean +/- standard error of the mean).

7

Figs. 4A-B depict an alignment of the relevant portions of the consensus amino acid sequences of the human IgG_1 CH1 domain (SEQ ID NO: 1), the human IgG_2 CH1 domain (SEQ ID NO: 2), the human IgG_3 CH1 domain (SEQ ID NO: 3), the human IgG_4 CH1 domain (SEQ ID NO: 4), the human κ C_L domain (SEQ ID NO: 5), and the human λ C_L domain (SEQ ID NO: 6), in alignment with the Fabv1b variant derived from an anti-CD18 antibody (SEQ ID NO: 7). In Figs. 4A-B, amino acid residues and/or positions of interest and of most importance for use as salvage receptor binding epitopes within the sequence of Fabv1b (*i.e.*, SEQ ID NOS: 8 and 9) are designated by underlining and asterisks, respectively.

Detailed Description of the Preferred Embodiments

I. Definitions

"Focal ischemic stroke" is defined herein as damage to the brain caused by interruption of the blood supply to a region thereof. The focal ischemic stroke of interest herein is generally caused by obstruction of any one or more of the "main cerebral arteries" (*e.g.* middle cerebral artery, anterior cerebral artery, posterior cerebral artery, internal carotid artery, vertebral artery or basilar artery), as opposed to secondary arteries or arterioles. The "arterial obstruction" is generally a single embolus or thrombus. Hence, focal ischemic stroke as defined herein is distinguished from the cerebral embolism stroke model of Bowes *et al.,Neurology* 45:815-819 (1995) in which a plurality of clot particles occlude secondary arteries or arterioles.

The expression "in the absence of removal of the arterial obstruction" when used throughout this application means that the arterial obstruction is essentially not removed by mechanical means (for example, by physically removing the obstruction as described in the transient stroke models described above) or by chemical means (such as removal of a thrombus or embolus using a thrombolytic agent; see, *e.g.,* Bowes *et al., Neurology* 45:815-819 (1995)) prior to a therapeutic benefit achieved by administration of the CD18 or CD11b antagonist (*i.e.,* the increase in cerebral blood flow and/or the reduction in infarct size). However, this term would encompass situations wherein the arterial obstruction is slightly reduced in size as a consequence of endogenous thrombolytic molecules dissolving part of the thrombus/embolus, provided that at least some (*e.g.,* about 50% and preferably about 80%) of the arterial obstruction remains intact following any such size reduction.

By "increasing cerebral blood flow or reducing infarct size" is meant the act of improving clinical outcome by inducing a statistically or physiologically significant increase in cerebral blood flow and/or a statistically or physiologically significant reduction in infarct size in a treated

mammal relative to an untreated mammal as determined using techniques which are well known in the art, such as vascular imaging, for example. Preferably cerebral blood flow as determined 2-4 hours after administration of the antagonist is increased by at least 30% and preferably at least 50% relative to an untreated mammal. Desirably, infarct size measured 48 hours after administration of the antagonist will be 20% less and preferably 50% less than that of an untreated mammal.

The term "CD18 antagonist" when used herein refers to a molecule which binds to CD18 (preferably human CD18) and inhibits or substantially reduces a biological activity of CD18. Normally, the antagonist will block (partially or completely) the ability of a cell (*e.g.* a neutrophil) expressing the CD18 subunit at its cell surface to bind to endothelium. Non-limiting examples of CD18 antagonists include antibodies, proteins, peptides, glycoproteins, glycopeptides, glycolipids, polysaccharides, oligosaccharides, nucleic acids, bioorganic molecules, peptidomimetics, pharmacological agents and their metabolites, transcriptional and translation control sequences, and the like. In the preferred embodiment of the invention, the CD18 antagonist is an antibody.

Examples of anti-CD18 antibodies include MHM23 (Hildreth *et al., Eur. J. Immunol.* 13:202-208 (1983)); M18/2 (IgG_{2a}; Sanches-Madrid *et al., J. Exp. Med.* 158:586 (1983)); H52 (American Type Culture Collection (ATCC) Deposit HB 10160); Mas191c and IOT18 (Vermot Desroches *et al., Scand. J. Immunol.* 33:277-286 (1991)); and NA-8 (WO 94/12214). The preferred antibody is one which binds to the CD18 epitope to which either MHM23 or H52 binds. Preferably the antibody has a high affinity for the CD18 polypeptide. In preferred embodiments, the antibody has an affinity for the CD18 antigen of about 4nM or less. Preferably, the affinity is about 3nM or less, and most preferably 1nM or less. In certain embodiments, the antibody may bind to a region in the extracellular domain of CD18 which associates with CD11b and the antibody may also dissociate α and β chains (*e.g.* the antibody may dissociate the CD11b and CD18 complex as is the case for the MHM23 antibody).

The term "CD11b antagonist" when used herein refers to a molecule which binds to CD11b and inhibits or substantially reduces a biological activity of CD11b. Normally, the antagonist will block (partially or completely) the ability of a cell (*e.g.* a neutrophil) expressing the CD11b subunit at its cell surface to bind to endothelium. Non-limiting examples of CD11b antagonists include antibodies, proteins, peptides, glycoproteins, glycopeptides, glycolipids, polysaccharides, oligosaccharides, nucleic acids, bioorganic molecules, peptidomimetics, pharmacological agents and their metabolites, transcriptional and translation control sequences, and the like. The preferred CD11b antagonist is an antibody, especially an anti-CD11b antibody

9

which binds human CD11b. Exemplary CD11b antibodies include MY904 (US Patent 4,840,793); 1B6c (see Zhang *et al., Brain Research* 698:79-85 (1995)); CBRN1/5 and CBRM1/19 (WO94/08620).

The term "antibody" is used in the broadest sense and specifically covers monoclonal antibodies, antibody compositions with polyepitopic specificity, bispecific antibodies, diabodies, and single-chain molecules, as well as antibody fragments (*e.g.*, Fab, $F(ab')_2$, and Fv), so long as they antagonize the biological activity of CD11b or CD18.

The term "monoclonal antibody" as used herein refers to an antibody obtained from a population of substantially homogeneous antibodies, *i.e.*, the individual antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Monoclonal antibodies are highly specific, being directed against a single antigenic site. Furthermore, in contrast to conventional (polyclonal) antibody preparations which typically include different antibodies directed against different determinants (epitopes), each monoclonal antibody is directed against a single determinant on the antigen. In addition to their specificity, the monoclonal antibodies are advantageous in that they are synthesized by the hybridoma culture, uncontaminated by other immunoglobulins. The modifier "monoclonal" indicates the character of the antibody as being obtained from a substantially homogeneous population of antibodies, and is not to be construed as requiring production of the antibody by any particular method. For example, the monoclonal antibodies to be used in accordance with the present invention may be made by the hybridoma method first described by Kohler *et al., Nature*, 256: 495 (1975), or may be made by recombinant DNA methods (see, *e.g.*, U.S. Patent No. 4,816,567). The "monoclonal antibodies" may also be isolated from phage antibody libraries using the techniques described in Clackson *et al., Nature,* 352:624-628 (1991) and Marks *et al., J. Mol. Biol.*, 222:581-597 (1991), for example.

The monoclonal antibodies herein specifically include "chimeric" antibodies (immunoglobulins) in which a portion of the heavy and/or light chain is identical with or homologous to corresponding sequences in antibodies derived from a particular species or belonging to a particular antibody class or subclass, while the remainder of the chain(s) is identical with or homologous to corresponding sequences in antibodies derived from another species or belonging to another antibody class or subclass, as well as fragments of such antibodies, so long as they exhibit the desired biological activity (U.S. Patent No. 4,816,567; Morrison *et al., Proc. Natl. Acad. Sci. USA*, 81:6851-6855 (1984)).

"Humanized" forms of non-human (*e.g.*, murine) antibodies are chimeric

10

immunoglobulins, immunoglobulin chains or fragments thereof (such as Fv, Fab, Fab', $F(ab')_2$ or other antigen-binding subsequences of antibodies) which contain minimal sequence derived from non-human immunoglobulin. For the most part, humanized antibodies are human immunoglobulins (recipient antibody) in which residues from a complementary-determining region (CDR) of the recipient are replaced by residues from a CDR of a non-human species (donor antibody) such as mouse, rat or rabbit having the desired specificity, affinity, and capacity. In some instances, Fv framework region (FR) residues of the human immunoglobulin are replaced by corresponding non-human residues. Furthermore, humanized antibodies may comprise residues which are found neither in the recipient antibody nor in the imported CDR or framework sequences. These modifications are made to further refine and optimize antibody performance. In general, the humanized antibody will comprise substantially all of at least one, and typically two, variable domains, in which all or substantially all of the CDR regions correspond to those of a non-human immunoglobulin and all or substantially all of the FR regions are those of a human immunoglobulin sequence. The humanized antibody optimally also will comprise at least a portion of an immunoglobulin constant region (Fc), typically that of a human immunoglobulin. For further details, see Jones *et al., Nature*, 321:522-525 (1986); Reichmann *et al., Nature*, 332:323-329 (1988); and Presta, *Curr. Op. Struct. Biol.*, 2:593-596 (1992). The humanized antibody includes a Primatized™ antibody wherein the antigen-binding region of the antibody is derived from an antibody produced by immunizing macaque monkeys with the antigen of interest.

"Single-chain Fv" or "sFv" antibody fragments comprise the V_H and V_L domains of antibody, wherein these domains are present in a single polypeptide chain. Generally, the Fv polypeptide further comprises a polypeptide linker between the V_H and V_L domains which enables the sFv to form the desired structure for antigen binding. For a review of sFv see Pluckthun in *The Pharmacology of Monoclonal Antibodies*, vol. 113, Rosenburg and Moore eds., Springer-Verlag, New York, pp. 269-315 (1994).

The term "diabodies" refers to small antibody fragments with two antigen-binding sites, which fragments comprise a heavy-chain variable domain (V_H) connected to a light-chain variable domain (V_L) in the same polypeptide chain (V_H - V_L). By using a linker that is too short to allow pairing between the two domains on the same chain, the domains are forced to pair with the complementary domains of another chain and create two antigen-binding sites. Diabodies are described more fully in, for example, EP 404,097; WO 93/11161; and Hollinger *et al., Proc. Natl. Acad. Sci. USA*, 90: 6444-6448 (1993).

As used herein, the term "salvage receptor binding epitope" refers to an epitope of the Fc region of an IgG molecule (*e.g.,* IgG_1, IgG_2, IgG_3, and IgG_4) that is responsible for increasing

11

the *in vivo* serum half-life of the IgG molecule.

"Treatment" refers to both therapeutic treatment and prophylactic or preventative measures. Those in need of treatment include those already with the disorder as well as those in which the disorder is to be prevented. This application is mostly concerned with treating those individuals who have been diagnosed as having suffered acute ischemic stroke.

"Mammal" for purposes of treatment refers to any animal classified as a mammal, including humans, domestic and farm animals, and zoo, sports, or pet animals, such as dogs, horses, cats, cows, *etc.* Preferably, the mammal is human.

A "thrombolytic agent" is a molecule which breaks up or dissolves a thrombus. Exemplary thrombolytic agents include streptokinase, acylated plasminogen-streptokinase activator complex (APSAC), urokinase, single-chain urokinase-plasminogen activator (scu-PA), thrombinlike enzymes from snake venoms such as ancrod (Bell, W. "Defribinogenating enzymes" In Colman *et al.,* (eds): *Hemostasis and Thrombosis* Lippincott, Philadelphia (1987) p. 886), tissue plasminogen activator (t-PA) and biologically active variants of each of the above. The preferred thrombolytic agent is t-PA.

In the context of the present invention, the terms "tissue plasminogen activator" and "t-PA" are used interchangeably and denote extrinsic (tissue type) plasminogen activator having at least two functional domains consisting of a protease domain that is capable of converting plasminogen to plasmin and an N-terminal region believed to be responsible for fibrin binding. These terms therefore include polypeptides containing these functional domains as part of the overall amino acid sequence, irrespective of their source and method of preparation (*e.g.* these terms cover vampire bat t-PAs as disclosed in EP 352,119). The terms "human tissue plasminogen activator" and "human t-PA" are used interchangeably and denote wild-type human tissue plasminogen activator and functional derivatives thereof. Examples of t-PA functional derivatives include those molecules with extended half-life and improved fibrin specificity as disclosed in WO 93/24635; N-terminally truncated t-PA variants (see EP 382,174); and C84S t-PA described in Suzuki *et al. J. Cardiovasc. Pharmacol.* 22:834-840 (1993), for example.

II. Modes for Carrying out the Invention

The invention provides a method for treating focal ischemic stroke, such as thromoboembolic stroke. In particular, cerebral blood flow can be increased and/or infarct size can be reduced in focal ischemic stroke by administering an effective amount of a CD11b and/or CD18 antagonist to the mammal having suffered the stroke. In this method, the arterial

obstruction is not removed prior to observation of the therapeutic benefit as defined herein, and as such the method does not require prior administration of a thrombolytic agent to the mammal in order to remove an embolus/thrombus and thereby increase cerebral blood flow and/or reduce infarct size.

It is contemplated that the CD18 or CD11a antagonist of the present invention will be administered to a patient as soon as possible once the condition of acute ischemic stroke has been diagnosed or is suggested by focal deficit on neurologic examination. Neurologic examination and, optionally, neuroimaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) (including diffusion weighted imaging (DWI) and perfusion imaging (PI)); vascular imaging (*e.g.,* duplex scanning and transcranial Doppler ultrasound and laser Doppler); angiography (*e.g.,* computerized digital subtraction angiography (DSA) and MR angiography) as well as other invasive or non-invasive techniques are available for the diagnosis of acute ischemic stroke.

Preferably, the CD18 or CD11a antagonist will be administered at least once or continuously at any time from immediately following to about 24 hours after the onset of stroke. In certain embodiments, the CD18 or CD11a antagonist is first administered to the patient at a time between about 15 minutes (or 30 minutes or 45 minutes) to about 5 hours (or 12 hours or 24 hours) from the onset of stroke. For example, the antagonist may be first administered by bolus dosage as soon as stroke is diagnosed, followed by a subsequent bolus dosage of the antagonist (*e.g.* 5-24 hours after the initial bolus dosage).

The preferred antagonist for use in the above method is humanized H52 antibody (huH52), especially the huH52 $F(ab')_2$ antibody fragment.

The sequence of the heavy chain of the huH52 Fab is:

EVQLVESGGGLVQPGGSLRLSCATSGYTFTEYTMHWMRQAPGKGLEWVAGINPKNGGTSH
NQRFMDRFTISVDKSTSTAYMQMNSLRAEDTAVYYCARWRGLNYGFDVRYFDVWGQGTLV
TVSSASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTVSWNSGALTSGVHTFPAVLQ
SSGLYSLSSVVTVPSSSLGTQTYICNVNHKPSNTKVDKKVEPKSCDKTHT (SEQ ID NO: 10).

The sequence of the light chain of the huH52 Fab is:

DIQMTQSPSSLSASVGDRVTITCRASQDINNYLNWYQQKPGKAPKLLIYYTSTLHSGVPSRFS
GSGSGTDYTLTISSLQPEDFATYYCQQGNTLPPTFGQGTKVEIKRTVAAPSVFIFPPSDEQLK
SGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQDSKDSTYSLSSTLTLSKADYE
KHKVYACEVTHQGLSSPVTKSFNRGEC (SEQ ID NO: 11).

In other embodiments, the full length IgG_2 huH52 antibody may be the molecule of choice. The heavy chain of the full length IgG_2 huH52 antibody has the sequence:

13

EVQLVESGGGLVQPGGSLRLSCATSGYTFTEYTMHWMRQAPGKGLEWVAGINPKNGGTSH
NQRFMDRFTISVDKSTSTAYMQMNSLRAEDTAVYYCARWRGLNYGFDVRYFDVWGQGTLV
TVSSASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTVSWNSGALTSGVHTFPAVLQ
SSGLYSLSSVVTVTSSNFGTQTYTCNVDHKPSNTKVDKTVERKCCVECPPCPAPPVAGPSVF
LFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVQFNWYVDGMEVHNAKTKPREEQFNSTFRV
VSVLTVVHQDWLNGKEYKCKVSNKGLPAPIEKTISKTKGQPREPQVYTLPPSREEMTKNQVS
LTCLVKGFYPSDIAVEWESNGQPENNYKTTPPMLDSDGSFFLYSKLTVDKSRWQQGNVFSC
SVMHEALHNHYTQKSLSLSPGK (SEQ ID NO:12).

The light chain of the full length IgG_2 huH52 antibody has the sequence:

DIQMTQSPSSLSASVGDRVTITCRASQDINNYLNWYQQKPGKAPKLLIYYTSTLHSGVPSRFS
GSGSGTDYTLTISSLQPEDFATYYCQQGNTLPPTFGQGTKVEIKRTVAAPSVFIFPPSDEQLK
SGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTEQDSKDSTYSLSSTLTLSKADYE
KHKVYACEVTHQGLSSPVTKSFNRGEC. (SEQ ID NO:11)

A description follows as to the production of the preferred antagonists (*i.e.* antibodies), long half-life antagonists, pharmaceutical formulations, modes for administration, as well as kits and articles of manufacture for use in the claimed methods. The description in relation to long half-life antagonists, pharmaceutical formulations and modes for administration is also relevant to the use of thrombolytic agents in certain embodiments of the invention.

A. Antibody Preparation

According to the preferred embodiment of the invention, the CD18 or CD11b antagonist is an antibody. Various antibodies which bind to CD18 and CD11b are available in the art. Furthermore, a description follows as to the production of anti-CD18 or anti-CD11b antibodies for use in the treatment of stroke as defined herein.

(i) Polyclonal antibodies.

Polyclonal antibodies are generally raised in animals by multiple subcutaneous (sc) or intraperitoneal (ip) injections of the relevant antigen and an adjuvant. It may be useful to conjugate the relevant antigen to a protein that is immunogenic in the species to be immunized, *e.g.*, keyhole limpet hemocyanin, serum albumin, bovine thyroglobulin, or soybean trypsin inhibitor using a bifunctional or derivatizing agent, for example, maleimidobenzoyl sulfosuccinimide ester (conjugation through cysteine residues), N-hydroxysuccinimide (through lysine residues), glutaraldehyde, succinic anhydride, $SOCl_2$, or $R^1N=C=NR$, where R and R^1 are different alkyl groups.

Animals are immunized against the antigen, immunogenic conjugates, or derivatives by

14

combining 1 mg or 1 μg of the peptide or conjugate (for rabbits or mice, respectively) with 3 volumes of Freund's complete adjuvant and injecting the solution intradermally at multiple sites. One month later the animals are boosted with 1/5 to 1/10 the original amount of peptide or conjugate in Freund's complete adjuvant by subcutaneous injection at multiple sites. Seven to 14 days later the animals are bled and the serum is assayed for antibody titer. Animals are boosted until the titer plateaus. Preferably, the animal is boosted with the conjugate of the same antigen, but conjugated to a different protein and/or through a different cross-linking reagent. Conjugates also can be made in recombinant cell culture as protein fusions. Also, aggregating agents such as alum are suitably used to enhance the immune response.

(ii) Monoclonal antibodies.

Monoclonal antibodies are obtained from a population of substantially homogeneous antibodies, *i.e.*, the individual antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Thus, the modifier "monoclonal" indicates the character of the antibody as not being a mixture of discrete antibodies.

For example, the monoclonal antibodies may be made using the hybridoma method first described by Kohler *et al., Nature,* 256:495 (1975), or may be made by recombinant DNA methods (U.S. Patent No. 4,816,567).

In the hybridoma method, a mouse or other appropriate host animal, such as a hamster, is immunized as hereinabove described to elicit lymphocytes that produce or are capable of producing antibodies that will specifically bind to the protein used for immunization. Alternatively, lymphocytes may be immunized *in vitro.* Lymphocytes then are fused with myeloma cells using a suitable fusing agent, such as polyethylene glycol, to form a hybridoma cell (Goding, *Monoclonal Antibodies: Principles and Practice*, pp.59-103 (Academic Press, 1986)).

The hybridoma cells thus prepared are seeded and grown in a suitable culture medium that preferably contains one or more substances that inhibit the growth or survival of the unfused, parental myeloma cells. For example, if the parental myeloma cells lack the enzyme hypoxanthine guanine phosphoribosyl transferase (HGPRT or HPRT), the culture medium for the hybridomas typically will include hypoxanthine, aminopterin, and thymidine (HAT medium), which substances prevent the growth of HGPRT-deficient cells.

Preferred myeloma cells are those that fuse efficiently, support stable high-level production of antibody by the selected antibody-producing cells, and are sensitive to a medium such as HAT medium. Among these, preferred myeloma cell lines are murine myeloma lines, such as those derived from MOPC-21 and MPC-11 mouse tumors available from the Salk

Institute Cell Distribution Center, San Diego, California USA, and SP-2 cells available from the American Type Culture Collection, Rockville, Maryland USA. Human myeloma and mouse-human heteromyeloma cell lines also have been described for the production of human monoclonal antibodies (Kozbor, *J. Immunol.*, 133:3001 (1984); Brodeur *et al., Monoclonal Antibody Production Techniques and Applications*, pp. 51-63 (Marcel Dekker, Inc., New York, 1987)).

Culture medium in which hybridoma cells are growing is assayed for production of monoclonal antibodies directed against the antigen. Preferably, the binding specificity of monoclonal antibodies produced by hybridoma cells is determined by immunoprecipitation or by an *in vitro* binding assay, such as radioimmunoassay (RIA) or enzyme-linked immunoabsorbent assay (ELISA).

The binding affinity of the monoclonal antibody can, for example, be determined by the Scatchard analysis of Munson *et al., Anal. Biochem.*, 107:220 (1980).

After hybridoma cells are identified that produce antibodies of the desired specificity, affinity, and/or activity, the clones may be subcloned by limiting dilution procedures and grown by standard methods (Goding, *Monoclonal Antibodies: Principles and Practice*, pp.59-103 (Academic Press, 1986)). Suitable culture media for this purpose include, for example, D-MEM or RPMI-1640 medium. In addition, the hybridoma cells may be grown *in vivo* as ascites tumors in an animal.

The monoclonal antibodies secreted by the subclones are suitably separated from the culture medium, ascites fluid, or serum by conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography.

DNA encoding the monoclonal antibodies is readily isolated and sequenced using conventional procedures (*e.g.*, by using oligonucleotide probes that are capable of binding specifically to genes encoding the heavy and light chains of murine antibodies). The hybridoma cells serve as a preferred source of such DNA. Once isolated, the DNA may be placed into expression vectors, which are then transfected into host cells such as *E. coli* cells, simian COS cells, Chinese hamster ovary (CHO) cells, or myeloma cells that do not otherwise produce immunoglobulin protein, to obtain the synthesis of monoclonal antibodies in the recombinant host cells. Review articles on recombinant expression in bacteria of DNA encoding the antibody include Skerra *et al., Curr. Opinion in Immunol.*, 5:256-262 (1993) and Plückthun, *Immunol. Revs.*, 130:151-188 (1992).

160

In a further embodiment, antibodies or antibody fragments can be isolated from antibody phage libraries generated using the techniques described in McCafferty *et al., Nature*, 348:552-554 (1990). Clackson *et al., Nature*, 352:624-628 (1991) and Marks *et al., J. Mol. Biol.*, 222:581-597 (1991) describe the isolation of murine and human antibodies, respectively, using phage libraries. Subsequent publications describe the production of high affinity (nM range) human antibodies by chain shuffling (Marks *et al., Bio/Technology*, 10:779-783 (1992)), as well as combinatorial infection and *in vivo* recombination as a strategy for constructing very large phage libraries (Waterhouse *et al., Nuc. Acids. Res.*, 21:2265-2266 (1993)). Thus, these techniques are viable alternatives to traditional monoclonal antibody hybridoma techniques for isolation of monoclonal antibodies.

The DNA also may be modified, for example, by substituting the coding sequence for human heavy- and light-chain constant domains in place of the homologous murine sequences (U.S. Patent No. 4,816,567 (Morrison, *et al., Proc. Natl Acad. Sci. USA*, 81:6851 (1984)), or by covalently joining to the immunoglobulin coding sequence all or part of the coding sequence for a non-immunoglobulin polypeptide.

Typically such non-immunoglobulin polypeptides are substituted for the constant domains of an antibody, or they are substituted for the variable domains of one antigen-combining site of an antibody to create a chimeric bivalent antibody comprising one antigen-combining site having specificity for an antigen and another antigen-combining site having specificity for a different antigen.

Chimeric or hybrid antibodies also may be prepared *in vitro* using known methods in synthetic protein chemistry, including those involving crosslinking agents. For example, immunotoxins may be constructed using a disulfide-exchange reaction or by forming a thioether bond. Examples of suitable reagents for this purpose include iminothiolate and methyl-4-mercaptobutyrimidate.

(iii) Humanized and human antibodies.

Methods for humanizing non-human antibodies are well known in the art. Generally, a humanized antibody has one or more amino acid residues introduced into it from a source which is non-human. These non-human amino acid residues are often referred to as "import" residues, which are typically taken from an "import" variable domain. Humanization can be essentially performed following the method of Winter and co-workers (Jones *et al., Nature*, 321:522-525 (1986); Riechmann *et al., Nature*, 332:323-327 (1988); Verhoeyen *et al., Science*, 239:1534-1536 (1988)), by substituting rodent CDRs or CDR sequences for the corresponding sequences

17

of a human antibody. Accordingly, such "humanized" antibodies are chimeric antibodies (U.S. Patent No. 4,816,567, wherein substantially less than an intact human variable domain has been substituted by the corresponding sequence from a non-human species. In practice, humanized antibodies are typically human antibodies in which some CDR residues and possibly some FR residues are substituted by residues from analogous sites in rodent antibodies.

The choice of human variable domains, both light and heavy, to be used in making the humanized antibodies is very important to reduce antigenicity. According to the so-called "best-fit" method, the sequence of the variable domain of a rodent antibody is screened against the entire library of known human variable-domain sequences. The human sequence which is closest to that of the rodent is then accepted as the human framework (FR) for the humanized antibody (Sims *et al., J. Immunol.*, 151:2296 (1993); Chothia *et al., J. Mol. Biol.*, 196:901 (1987)). Another method uses a particular framework derived from the consensus sequence of all human antibodies of a particular subgroup of light or heavy chains. The same framework may be used for several different humanized antibodies (Carter *et al., Proc. Natl. Acad. Sci. USA*, 89:4285 (1992); Presta *et al., J. Immnol.*, 151:2623 (1993)).

It is further important that antibodies be humanized with retention of high affinity for the antigen and other favorable biological properties. To achieve this goal, according to a preferred method, humanized antibodies are prepared by a process of analysis of the parental sequences and various conceptual humanized products using three-dimensional models of the parental and humanized sequences. Three-dimensional immunoglobulin models are commonly available and are familiar to those skilled in the art. Computer programs are available which illustrate and display probable three-dimensional conformational structures of selected candidate immunoglobulin sequences. Inspection of these displays permits analysis of the likely role of the residues in the functioning of the candidate immunoglobulin sequence, *i.e.*, the analysis of residues that influence the ability of the candidate immunoglobulin to bind its antigen. In this way, FR residues can be selected and combined from the recipient and import sequences so that the desired antibody characteristic, such as increased affinity for the target antigen(s), is achieved. In general, the CDR residues are directly and most substantially involved in influencing antigen binding.

Alternatively, it is now possible to produce transgenic animals (*e.g.*, mice) that are capable, upon immunization, of producing a full repertoire of human antibodies in the absence of endogenous immunoglobulin production. For example, it has been described that the homozygous deletion of the antibody heavy-chain joining region (J_H) gene in chimeric and germ-line mutant mice results in complete inhibition of endogenous antibody production. Transfer of

18

the human germ-line immunoglobulin gene array in such germ-line mutant mice will result in the production of human antibodies upon antigen challenge. See, *e.g.*, Jakobovits *et al., Proc. Natl. Acad. Sci. USA*, 90:2551 (1993); Jakobovits *et al., Nature*, 362:255-258 (1993); Bruggermann *et al., Year in Immuno.*, 7:33 (1993). Human antibodies can also be derived from phage- display libraries (Hoogenboom *et al., J. Mol. Biol.*, 227:381 (1991); Marks *et al., J. Mol. Biol.*, 222:581-597 (1991)).

(iv) Bispecific antibodies

Bispecific antibodies (BsAbs) are antibodies that have binding specificities for at least two different epitopes. Exemplary BsAbs may bind to two different epitopes of the CD18 antigen or may bind both CD18 and CD11b. Such antibodies can be derived from full length antibodies or antibody fragments (*e.g.* $F(ab')_2$ bispecific antibodies).

Methods for making bispecific antibodies are known in the art. Traditional production of full length bispecific antibodies is based on the coexpression of two immunoglobulin heavy chain-light chain pairs, where the two chains have different specificities (Millstein *et al., Nature*, 305:537-539 (1983)). Because of the random assortment of immunoglobulin heavy and light chains, these hybridomas (quadromas) produce a potential mixture of 10 different antibody molecules, of which only one has the correct bispecific structure. Purification of the correct molecule, which is usually done by affinity chromatography steps, is rather cumbersome, and the product yields are low. Similar procedures are disclosed in WO 93/08829, published 13 May 1993, and in Traunecker *et al., EMBO J.*, 10:3655-3659 (1991).

According to a different and more preferred approach, antibody variable domains with the desired binding specificities (antibody-antigen combining sites) are fused to immunoglobulin constant domain sequences. The fusion preferably is with an immunoglobulin heavy chain constant domain, comprising at least part of the hinge, CH2, and CH3 regions. It is preferred to have the first heavy-chain constant region (CH1) containing the site necessary for light chain binding, present in at least one of the fusions. DNAs encoding the immunoglobulin heavy chain fusions and, if desired, the immunoglobulin light chain, are inserted into separate expression vectors, and are co-transfected into a suitable host organism. This provides for great flexibility in adjusting the mutual proportions of the three polypeptide fragments in embodiments when unequal ratios of the three polypeptide chains used in the construction provide the optimum yields. It is, however, possible to insert the coding sequences for two or all three polypeptide chains in one expression vector when the expression of at least two polypeptide chains in equal ratios results in high yields or when the ratios are of no particular significance.

In a preferred embodiment of this approach, the bispecific antibodies are composed of a hybrid immunoglobulin heavy chain with a first binding specificity in one arm, and a hybrid immunoglobulin heavy chain-light chain pair (providing a second binding specificity) in the other arm. It was found that this asymmetric structure facilitates the separation of the desired bispecific compound from unwanted immunoglobulin chain combinations, as the presence of an immunoglobulin light chain in only one half of the bispecific molecule provides for a facile way of separation. This approach is disclosed in WO 94/04690 published March 3, 1994. For further details of generating bispecific antibodies see, for example, Suresh *et al., Methods in Enzymology*, 121:210 (1986). Using such techniques, a bispecific molecule which combines a thrombolytic agent such as t-PA and an anti-CD18 or anti-CD11b antibody can be prepared for use in the treatment of stroke as defined herein.

Bispecific antibodies include cross-linked or "heteroconjugate" antibodies. For example, one of the antibodies in the heteroconjugate can be coupled to avidin, the other to biotin. Such antibodies have, for example, been proposed to target immune system cells to unwanted cells (US Patent No. 4,676,980), and for treatment of HIV infection (WO 91/00360, WO 92/200373, and EP 03089). Heteroconjugate antibodies may be made using any convenient cross-linking methods. Suitable cross-linking agents are well known in the art, and are disclosed in US Patent No. 4,676,980, along with a number of cross-linking techniques.

Techniques for generating bispecific antibodies from antibody fragments have also been described in the literature. The following techniques can also be used for the production of bivalent antibody fragments which are not necessarily bispecific. For example, Fab' fragments recovered from *E. coli* can be chemically coupled *in vitro* to form bivalent antibodies. See, Shalaby *et al., J. Exp. Med.*, 175:217-225 (1992).

Various techniques for making and isolating bivalent antibody fragments directly from recombinant cell culture have also been described. For example, bivalent heterodimers have been produced using leucine zippers. Kostelny *et al., J. Immunol.*, 148(5):1547-1553 (1992). The leucine zipper peptides from the Fos and Jun proteins were linked to the Fab' portions of two different antibodies by gene fusion. The antibody homodimers were reduced at the hinge region to form monomers and then re-oxidized to form the antibody heterodimers. The "diabody" technology described by Hollinger *et al., Proc. Natl. Acad. Sci. USA*, 90:6444-6448 (1993) has provided an alternative mechanism for making bispecific/bivalent antibody fragments. The fragments comprise a heavy-chain variable domain (V_H) connected to a light-chain variable domain (V_L) by a linker which is too short to allow pairing between the two domains on the same chain. Accordingly, the V_H and V_L domains of one fragment are forced to pair with the

complementary V_L and V_H domains of another fragment, thereby forming two antigen-binding sites. Another strategy for making bispecific/bivalent antibody fragments by the use of single-chain Fv (sFv) dimers has also been reported. See Gruber *et al., J. Immunol.*, 152:5368 (1994).

B. Long half-life antagonists

In certain embodiments of the invention, it is desirable to use CD18 or CD11b antagonists engineered to have an enhanced half-life in the serum of a mammal treated therewith. For example, this may be achieved by (i) incorporating a salvage receptor binding epitope of the Fc region of an IgG into the antagonist so as to increase its circulatory half-life, but without disrupting its biological activity or (ii) covalently binding a nonproteinaceous polymer to the antagonist. These exemplary techniques will be described briefly below:

(i) Antagonist-salvage receptor binding epitope fusions.

Incorporation of a salvage receptor binding epitope into the antagonist can take place by any means, such as by mutation of the appropriate region in the antagonist of interest to mimic the Fc region or by incorporating the epitope into a peptide tag that is then fused to the antagonist at either end or in the middle or by DNA or peptide synthesis.

A systematic method for preparing such an antagonist variant having an increased *in vivo* half-life comprises several steps. The first involves identifying the sequence and conformation of a salvage receptor binding epitope of an Fc region of an IgG molecule. Once this epitope is identified, the sequence of the antagonist of interest is modified to include the sequence and conformation of the identified binding epitope. After the sequence is mutated, the antagonist variant is tested to see if it has a longer *in vivo* half-life than that of the original antagonist. If the antagonist variant does not have a longer *in vivo* half-life upon testing, its sequence is further altered to include the sequence and conformation of the identified binding epitope. The altered antagonist is tested for longer *in vivo* half-life, and this process is continued until a molecule is obtained that exhibits a longer *in vivo* half-life.

The salvage receptor binding epitope being thus incorporated into the antagonist of interest is any suitable such epitope as defined above, and its nature will depend, *e.g.*, on the type of antagonist being modified. The transfer is made such that the antagonist of interest is still able to antagonize the biological activity of CD11b or CD18.

Where the antagonist of interest is an antibody, it contains an Ig domain or Ig-like domain and the salvage receptor binding epitope is placed so that it is located within this Ig domain or

Ig-like domain. More preferably, the epitope constitutes a region wherein any one or more amino acid residues from one or two loops of the Fc domain are transferred to an analogous position of the Ig domain or Ig-like domain of the antibody. Even more preferably, three or more residues from one or two loops of the Fc domain are transferred. Still more preferred, the epitope is taken from the CH2 domain of the Fc region (*e.g.*, of an IgG) and transferred to the CH1, CH3, or V_H region, or more than one such region, of an Ig or to a Ig-like domain. Alternatively, the epitope is taken from the CH2 domain of the Fc region and transferred to the C_L region or V_L region, or both, of an Ig or to an Ig-like domain of the antagonist of interest.

For example, for purposes of discussing variants wherein the polypeptide of interest is an antibody, reference is made to Figs. 4A-B, which illustrates the relevant consensus primary structures of various Igs, *i.e.,* human IgG_1 CH1 domain, human IgG_2 CH1 domain, human IgG_3 CH1 domain, human IgG_4 CH1 domain, human κC_L domain, and human λC_L domain, as well as the specific sequence for Fabv1b, a preferred anti-CD18 Fab variant herein. Further, Figs. 4A-B indicates the residues of Fabv1b that are of interest and of most importance. In a preferred embodiment, the residues of importance are those with an asterisk in Figs. 4A-B, *i.e.*, in one loop of Fabv1b, MIS with a T residue one amino acid C-terminal to MIS, and in another loop of Fabv1b, HQN with a D residue two amino acids C-terminal to HQN and a K residue one amino acid C-terminal to the D residue.

In one most preferred embodiment, the salvage receptor binding epitope comprises the sequence (5' to 3'): PKNSSMISNTP (SEQ ID NO:8), and optionally further comprises a sequence selected from the group consisting of HQSLGTQ (SEQ ID NO: 13), HQNLSDGK (SEQ ID NO:9), HQNISDGK (SEQ ID NO:14), or VISSHLGQ (SEQ ID NO:15), particularly where the antagonist of interest is a Fab or $F(ab')_2$.

(ii) Antagonist-polymer conjugates.

The nonproteinaceous polymer of choice for this purpose is ordinarily is a hydrophilic synthetic polymer, *i.e.*, a polymer not otherwise found in nature. However, polymers which exist in nature and are produced by recombinant or *in vitro* methods are useful, as are polymers which are isolated from native sources. Hydrophilic polyvinyl polymers fall within the scope of this invention, *e.g.* polyvinylalcohol and polyvinylpyrrolidone. Particularly useful are polyalkylene ethers such as polyethylene glycol (PEG); polyelkylenes such as polyoxyethylene, polyoxypropylene, and block copolymers of polyoxyethylene and polyoxypropylene (Pluronics); polymethacrylates; carbomers; branched or unbranched polysaccharides which comprise the saccharide monomers D-mannose, D- and L-galactose, fucose, fructose, D-xylose, L-arabinose, D-glucuronic acid, sialic acid, D-galacturonic acid, D-mannuronic acid (*e.g.* polymannuronic acid,

22

or alginic acid), D-glucosamine, D-galactosamine, D-glucose and neuraminic acid including homopolysaccharides and heteropolysaccharides such as lactose, amylopectin, starch, hydroxyethyl starch, amylose, dextrane sulfate, dextran, dextrins, glycogen, or the polysaccharide subunit of acid mucopolysaccharides, *e.g.* hyaluronic acid; polymers of sugar alcohols such as polysorbitol and polymannitol; heparin or heparon. The polymer prior to cross-linking need not be, but preferably is, water soluble, but the final conjugate must be water soluble. In addition, the polymer should not be highly immunogenic in the conjugate form, nor should it possess viscosity that is incompatible with intravenous infusion or injection if it is intended to be administered by such routes.

Preferably the polymer contains only a single group which is reactive. This helps to avoid cross-linking of protein molecules. However, it is within the scope herein to optimize reaction conditions to reduce cross-linking, or to purify the reaction products through gel filtration or chromatographic sieves to recover substantially homogenous derivatives.

The molecular weight of the polymer may desirably range from about 100 to 500,000, and preferably is from about 1,000 to 20,000. The molecular weight chosen will depend upon the nature of the polymer and the degree of substitution. In general, the greater the hydrophilicity of the polymer and the greater the degree of substitution, the lower the molecular weight that can be employed. Optimal molecular weights will be determined by routine experimentation.

The polymer generally is covalently linked to the antagonist though a multifunctional crosslinking agent which reacts with the polymer and one or more amino acid or sugar residues of the antagonist to be linked. However, it is within the scope of the invention to directly crosslink the polymer by reacting a derivatized polymer with the hybrid, or *vice versa*.

Covalent binding to amino groups is accomplished by known chemistries based upon cyanuric chloride, carbonyl diimidazole, aldehyde reactive groups (PEG alkoxide plus diethyl acetal of bromoacetaldehyde; PEG plus DMSO and acetic anhydride, or PEG chloride plus the phenoxide of 4-hydroxybenzaldehyde, succinimidyl active esters, activated dithiocarbonate PEG, 2,4,5-trichlorophenylcloroformate or P-nitrophenylcloroformate activated PEG). Carboxyl groups are derivatized by coupling PEG-amine using carbodiimide.

Polymers are conjugated to oligosaccharide groups by oxidation using chemicals, *e.g.* metaperiodate, or enzymes, *e.g.* glucose or galactose oxidase, (either of which produces the aldehyde derivative of the carbohydrate), followed by reaction with hydrazide or amino derivatized polymers, in the same fashion as is described by Heitzmann *et al., Proc. Natl Acad. Sci. USA* 71:3537-41 (1974) or Bayer *et al., Methods in Enzymology* 62:310 (1979), for the labeling of oligosaccharides with biotin or avidin. Further, other chemical or enzymatic methods

which have been used heretofore to link oligosaccharides are particularly advantageous because, in general, there are fewer substitutions than amino acid sites for derivatization, and the oligosaccharide products thus will be more homogenous. The oligosaccharide substituents also are optionally modified by enzyme digestion to remove sugars, *e.g.* by neuraminidase digestion, prior to polymer derivatization.

The polymer will bear a group which is directly reactive with an amino acid side chain, or the N- or C-terminus of the antagonist linked, or which is reactive with the multifunctional cross-linking agent. In general, polymers bearing such reactive groups are known for the preparation of immobilized proteins. In order to use such chemistries here, one should employ a water soluble polymer otherwise derivatized in the same fashion as insoluble polymers heretofore employed for protein immobilization. Cyanogen bromide activation is a particularly useful procedure to employ in crosslinking polysaccharides.

"Water soluble" in reference to the starting polymer means that the polymer or its reactive intermediate used for conjugation is sufficiently water soluble to participate in a derivatization reaction. "Water soluble" in reference to the polymer conjugate means that the conjugate is soluble in physiological fluids such as blood.

The degree of substitution with such a polymer will vary depending upon the number of reactive sites on the antagonist, whether all or a fragment of the antagonist is used, whether the antagonist is a fusion with a heterologous protein (*e.g.* anti-CD18 antibody fused to a salvage receptor binding epitope), the molecular weight, hydrophilicity and other characteristics of the polymer, and the particular antagonist derivatization sites chosen. In general, the conjugate contains about from 1 to 10 polymer molecules, while any heterologous sequence may be substituted with an essentially unlimited number of polymer molecules so long as the desired activity is not significantly adversely affected. The optimal degree of cross-linking is easily determined by an experimental matrix in which the time, temperature and other reaction conditions are varied to change the degree of substitution, after which the ability of the conjugates to function in the desired fashion is determined.

The polymer, *e.g.* PEG, is cross-linked by a wide variety of methods known *per se* for the covalent modification of proteins with nonproteinaceous polymers such as PEG.

The long half-life conjugates of this invention are separated from the unreacted starting materials by gel filtration. Heterologous species of the conjugates are purified from one another in the same fashion. The polymer also may be water-insoluble, as a hydrophilic gel.

C. Pharmaceutical Formulations

Therapeutic formulations of the CD11b or CD18 antagonist are prepared for storage by

mixing the antagonist having the desired degree of purity with optional physiologically acceptable carriers, excipients or stabilizers (*Remington's Pharmaceutical Sciences* 16th edition, Osol, A. Ed. (1980)), in the form of lyophilized formulations or aqueous solutions. Acceptable carriers, excipients or stabilizers are nontoxic to recipients at the dosages and concentrations employed, and include buffers such as phosphate, citrate and other organic acids; antioxidants including ascorbic acid; low molecular weight (less than about 10 residues) polypeptides; proteins, such as serum albumin, gelatin or immunoglobulins; amino acids such as glycine, glutamine, asparagine, histidine, arginine or lysine; monosaccharides, disaccharides and other carbohydrates including glucose, mannose, trehalose or dextrins; chelating agents such as EDTA; sugar alcohols such as mannitol or sorbitol; salt-forming counterions such as sodium; and/or nonionic surfactants such as Tween, Pluronics or PEG.

The active ingredients may also be entrapped in microcapsules prepared, for example, by coacervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsules and poly-(methylmethacylate) microcapsules, respectively, in colloidal drug delivery systems (for example, liposomes, albumin microspheres, microemulsions, nano-particles and nanocapsules) or in macroemulsions. Such techniques are disclosed in *Remington's Pharmaceutical Sciences* 16th edition, Osol, A. Ed. (1980).

The formulations to be used for *in vivo* administration must be sterile. This is readily accomplished by filtration through sterile filtration membranes, prior to or following lyophilization and reconstitution.

Sustained-release preparations may be prepared. Suitable examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the CD18 or CD11b antagonist, which matrices are in the form of shaped articles, *e.g.* films, or microcapsules. Examples of sustained-release matrices include polyesters, hydrogels (for example, poly(2-hydroxyethyl-methacrylate), or poly(vinylalcohol)), polylactides (U.S. Pat. No. 3,773,919), copolymers of L-glutamic acid and γ ethyl-L-glutamate, non-degradable ethylene-vinyl acetate, degradable lactic acid-glycolic acid copolymers such as the Lupron Depot™ (injectable microspheres composed of lactic acid-glycolic acid copolymer and leuprolide acetate), and poly-D-(-)-3-hydroxybutyric acid. While polymers such as ethylene-vinyl acetate and lactic acid-glycolic acid enable release of molecules for over 100 days, certain hydrogels release proteins for shorter time periods. When encapsulated antibodies remain in the body for a long time, they may denature or aggregate as a result of exposure to moisture at 37°C, resulting in a loss of biological activity and possible changes in immunogenicity. Rational strategies can be devised for stabilization depending on the mechanism involved. For example, if the aggregation

mechanism is discovered to be intermolecular S-S bond formation through thio-disulfide interchange, stabilization may be achieved by modifying sulfhydryl residues, lyophilizing from acidic solutions, controlling moisture content, using appropriate additives, and developing specific polymer matrix compositions.

Sustained-release CD18 or CD11b antagonist compositions also include liposomally entrapped antagonists. Liposomes containing the CD18 or CD11b antagonist are prepared by methods known in the art, such as described in Epstein *et al., Proc. Natl. Acad. Sci. USA*, 82:3688 (1985); Hwang *et al., Proc. Natl Acad. Sci. USA*, 77:4030 (1980); and U.S. Pat. Nos. 4,485,045 and 4,544,545. Ordinarily, the liposomes are the small (about 200-800 Angstroms) unilamelar type in which the lipid content is greater than about 30 mol.% cholesterol, the selected proportion being adjusted for the optimal CD18 or CD11b antagonist therapy. Liposomes with enhanced circulation time are disclosed in U.S. Patent No. 5,013,556.

D. Modes for Administration

The CD18 or CD11b antagonists of the invention are administered to a mammal, preferably a human, in accord with known methods, such as intravenous administration as a bolus or by continuous infusion over a period of time, by intramuscular, intraperitoneal, intracerobrospinal, subcutaneous, intra-articular, intrasynovial, intrathecal, oral, topical, or inhalation routes. Intravenous administration of the antagonist is preferred.

The appropriate dosage of CD18 or CD11b antagonist will depend on the nature of the stroke to be treated, the severity and course of the stroke, whether the antagonist is administered for preventive or therapeutic purposes, previous therapy, the patient's clinical history and response to the CD18 or CD11b antagonist, and the discretion of the attending physician. The CD18 or CD11b antagonist is suitably administered to the patient at one time or over a series of treatments and may be administered to the patient at any time from diagnosis onwards. For example, the antagonist may be administered at a time between about 15, 30 or 45 minutes to about 5 hours, 12 hours or 24 hours from the onset of stroke. In preferred embodiments, the initial dose is followed by at least one subsequent dose (*e.g.,* from 5 to 24 hours after the initial dose). In certain situations, CD11b antagonist and CD18 antagonist are co-administered to the mammal.

Where the antagonist is an antibody, from about 100µg/kg to about 20mg/kg, and preferably from about 500µg/kg to about 5 mg/kg, and most preferably from about 1mg/kg to about 3mg/kg of the anti-CD18 or anti-CD11b antibody is an initial candidate dosage for administration to the patient, whether, for example, by one or more separate administrations, or by continuous infusion. However, other dosage regimens may be useful. The progress of this

therapy is easily monitored by conventional techniques and assays elaborated herein.

E. Kits and Articles of Manufacture

In another embodiment of the invention, there are provided articles of manufacture and kits containing materials useful for improving clinical outcome in stroke by increasing cerebral blood flow and/or reducing infarct size. The article of manufacture comprises a container with a label. Suitable containers include, for example, bottles, vials, and test tubes. The containers may be formed from a variety of materials such as glass or plastic. The container holds a composition which is effective for treating stroke as defined herein and may have a sterile access port (for example the container may be an intravenous solution bag or a vial having a stopper pierceable by a hypodermic injection needle). The active agent in the composition is a CD11b or CD18 antagonist. The label on the container indicates that the composition is used for treating stroke as described above, and may also indicate directions for *in vivo* use, such as those described above.

The kit of the invention comprises the container described above and a second container comprising a pharmaceutically-acceptable buffer, such as phosphate-buffered saline, Ringer's solution and dextrose solution. It may further include other materials desirable from a commercial and user standpoint, including other buffers, diluents, filters, needles, syringes, and package inserts with instructions for use.

The following examples are offered by way of illustration and not by way of limitation. The disclosures of all citations in the specification are expressly incorporated herein by reference.

EXAMPLE

This study investigated the effect of anti-CD18 antibody (MHM23) and t-PA in a rabbit model of thromboembolic stroke. In this model, a single blood clot is introduced into the middle cerebral and posterior communicating arteries (which are "main cerebral arteries"). The arterial obstruction (*i.e.*, the clot) remains in place throughout the experiment (unless it is enzymatically removed by t-PA). The following rabbit model is thought to correlate well with the physiological progression of thromboembolic stroke in humans.

Materials and Methods

The rabbit model of thromboembolic stroke used in the current study has been previously described in detail (Bednar *et al., Neurol. Res.,* 16:129-132 (1994); Gross *et al., Stroke,* 24:558-562 (1993); Kohut *et al., Stroke,* 23:93-97 (1992); Wilson *et al., Neurosurgery,* 31:929-934

(1992)). See, also, Gross *et al., Neurosurgery*, 36(6):1172-1177 (1995).

Briefly, New Zealand white rabbits (Charles River, CA) (both males and females; 3.0-3.5kg) were anesthetized with the solution of ketamine (50mg/kg; Aveco Co., Fort Dodge, IA), acepromazine (20 mg, Aveco Co.), and xylazine (5 mg/kg; Mobay Corp., Shawnee, KS), a solution that was subsequently used to maintain sufficient anesthesia for painless surgery (as determined by responses to various physiological and autonomic stimuli, including mean arterial pressure and response to a paw being pinched). After an incision was made in the right femoral triangle to expose the femoral vein and artery, the femoral artery was cannulated with a PE-90 catheter (BD Co., Parsippany, NJ), to which was attached a platinum-iridium electrode. This catheter-electrode permitted the continuous measuring of mean arterial pressure and blood sampling for measurement of arterial blood gases (ABG) (pH, PCO_2, PO_2), hematocrit, and glucose and for determination of hydrogen washout to assess the rCBF by the hydrogen clearance technique (Young, *Stroke,* 11:552-564 (1980)). After the femoral vein was cannulated with PE-90 tubing for drug infusions, a midline scalp incision was made to expose the calvarium. Bilateral craniectomies were performed and the following were placed; 30-gauge platinum-iridium electrodes to monitor the regional cerebral blood flow (rCBF); a fiberoptic, epidural intracranial pressure (ICP) monitor (Princeton Medical Corp., Hudson, NH); and a temperature sensor (Yellow Springs Instruments, Yellow Springs, OH) to measure brain temperature. All cranial instrumentation was carefully fixed in place with fast-setting epoxy. Through a midline neck incision, the animal was tracheostomized and mechanically ventilated. Both depth and rate of ventilation were modified as needed to maintain ABGs within physiological range.

Throughout the experiment, the brain and core temperatures, mean arterial pressure, and ICP were continuously measured. Additionally, the following parameters were measured before embolization (baseline), at the time of embolization, and hourly after embolization; the rCBF, hematocrit, glucose, and ABG. The mean arterial pressures were kept between 50 and 60 mm Hg throughout the experiment. Fluids (Ringer's lactate or packed cells) were given intravenously as needed (approximately 2-4 ml/kg/h) to maintain euvolemia. Core and brain temperatures were maintained within 1°C of baseline by using heating blankets and heating lamps.

The autologous clot was prepared by mixing the whole blood (1 ml) with 50 mg of tin granules. The clot was introduced into the PE-90 tubing pretreated with thrombin and was allowed to mature at room temperature.

After tracheostomy, the region of the bifurcation of the common carotid artery was identified, followed by 30 to 60 minutes of equilibration, during which baseline values were obtained. All surgery was completed within 2 hours. Once all the baseline values were

obtained, the proximal internal carotid artery and the distal common carotid artery were transiently isolated from the circulation. An arteriotomy was then performed, and the autologous clot embolus was delivered to the anterior circulation of the brain via a catheter advanced into the proximal internal carotid artery. Once embolized, both the proximal internal carotid artery and distal common carotid artery were again isolated from the circulation and an arteriorrhaphy was performed by using 10-0 interrupted nylon sutures. A Philip's dental x-ray machine was used to obtain a submental-vertex radiograph that verified placement of the tin-tagged clot. Embolized clots were noted within the middle cerebral and posterior communicating arteries.

t-PA or a saline solution (0.9% saline) was administered intravenously by continuous infusion from hours 3-5 after the embolization at a total dose of 6.3 mg/kg. MHM23 (2 mg/kg) was administered by bolus dosage 1 hour after embolization. In each instance, the experiment continued for 7 hours after embolization. Submental-vertex radiographs were obtained after embolization and at the end of the experiment. Immediately after the embolization, the rCBF was measured again; the experiment was continued if the rCBF was $\leq$15 ml/100 g/ min in any of the three electrodes in the embolized hemisphere (Jones *et al., J. Neurosurg.,* 54:773-782 (1981)).

At the end of the experiment, the animals were killed with an overdose of sodium pentobarbital (150 mg/kg), a procedure recognized as acceptable and painless, according to the euthanasia guidelines of the American Veterinary Medical Association. Bilateral thoracotomies were performed in accordance with procedures outlined by the University of Vermont Institutional Animal Care and Utilization Committee. The brain was harvested rapidly and examined grossly for the presence and position of residual clot. The brain was cut into 2-mm slices in a bread-loaf fashion and incubated in triphenyltetrazolium chloride dye to define the size of the brain infarct (Bose *et al., Stroke,* 19:28-37 (1988)). This method has been shown to be an acceptable means of determining the size of a brain infarct in our rabbit model and correlates well with hematoxylin and eosin staining (Bednar *et al., Neurol. Res.,* 16:129-132 (1994)). Each brain slice was carefully traced onto clear acetate sheets for later planimetric determination of the infarct size, for which an IBM image analyzer was used. The infarct size was determined according to the modification described by Lin *et al., Stroke,* 24:117-121 (1993). In this method, the region of the infarct is determined by subtracting the volume of the noninfarcted part of the embolized hemisphere from the entire volume of the nonembolized hemisphere. This modification takes into account that the volume of a brain infarct may be overestimated because of associated swelling.

The analysis of variance for repeated measures was used to analyze the hematocrit, glucose, ABG, rCBF, and ICP in the control and treated groups. If significance was noted, the

values of these variables immediately before the t-PA and/or MHM23 administration were then compared by the Student's *t* test. When necessary, the analysis of covariance was used to compare the control and treated groups. After a significant treatment-by-time interaction, individual contrasts were used to compare the treatment means at each time point; that is, if a significant treatment-by-time interaction was noted, the treatment effects were examined at each time point. The infarct size and specific gravities of the brain were compared (treated versus control) by the Student's *t* test. All the results were two-sided and were evaluated by using $\alpha = 0.05$.

Results

The results of the above experiment are depicted in Figs. 1-3. As shown in Figs. 1 and 2, administration of anti-CD18 antibody alone, lead to a significant increase in cerebral blood flow as well as a significant reduction in infarct size relative to control. Fig. 3 shows that anti-CD18 antibody alone, t-PA alone, or a combination of these two agents tend to reduce intracranial pressure (ICP) at 6-7 hours. Furthermore, the experiments show that anti-CD18 antibody is compatable with t-PA and improves the outcome of t-PA when given at 3-5 hours after installation of the clot into the cerebral circulation.

The increase in cerebral blood flow and the reduction in infarct size observed in the above experiments are thought to be predictive of an improvement in clinical outcome as measured by a standard stroke scale. Accordingly, this application provides a method for improving clinical outcome in patients having suffered stroke as defined herein.

The model described in this example differs from that previously described in Bednar *et al.*, Stroke 23(1):152 (1992) in that the animals in the study were not subjected to extraneous systemic hypotension (by reducing the mean arterial pressure in the animal to 30 mmHg by controlled exsanguination). Also, the anti-CD18 antibody was given more than 30 minutes after the thromboembolic event and the dose was different.